between the disturbed areas and the structural features of the Alps will be looked for with interest.

W. M. DAVIS.

THE CAUSES OF EARTHQUAKES.[1]

I HAVE followed with much interest the details upon the recent earthquakes, which the newspapers have published; but this question is so intricate, so difficult, that I assure you I should not have undertaken its investigation had I thought any other person would have been willing to do so. Meanwhile, at the academy, the question is growing in importance, geologists, geodesists, and others having taken it up with considerable enthusiasm. Under these conditions, I have thought that I ought not to draw back. Nevertheless, I am not without a certain apprehension. Indeed, the question of earthquakes is one of the vaguest. Data are hitherto wanting, but there is no lack of theories; for as in medicine, when there are many remedies for one disease, it is frequently the case that neither is really good, so in geology, in terrestrial physics, when many theories are put forward to explain a phenomenon, it is necessary to cast aside each, and say that none is absolutely sufficient. I start, then, with a certain hesitation; and yet, when one accepts an appointment to study facts of this sort, it seems to me necessary to have in mind some theory, true or false, and to adopt it more or less boldly, free to abandon it after contradiction.

I start, then, with a certain idea which I expect to verify or invalidate. I do not propose to tell you what it is: I will simply ask your permission, before giving my plan of studies, to point out in a few words the current theories to account for earthquakes.

There are four principal ones. They are very old. We find them in the Greek authors, and perhaps, if one were to search carefully, they would be found among East-Indian traditions. The first is based upon the supposition, that, under the solid crust of the earth, the sudden generation of gases and vapors causes subterranean explosions; and it is the effect of these shocks that we feel on the surface. This would be in a way comparable to an explosion of dynamite taking place at a great depth. I need not discuss these theories, yet I may say that perhaps this one is true when applied to earthquakes in the neighborhood of volcanoes. It is certain, indeed, that as soon as the earth opens, great quantities of gas are liberated from beneath the surface, where in some way they have been generated and furnished with extraordinary power.

But even if this theory is probable with regard to volcanic earthquakes, I think that it would be difficult to apply it to those in Spain.

A second theory has been proposed by a learned physicist, Alexis Perrey. It is based upon the supposition that the combined influence of the sun and moon, acting upon the liquid parts beneath the surface, produces tides analogous to those on the surface of the earth. These vast tides of liquid fire at certain favorable movements, striking upon the solid external crust, cause the earthquake shocks. I also abandon this theory, for I do not think it can apply to Spain.

There remain two others, one that of Scheuchzer, a distinguished *savant*, at once paleontologist, geologist, and physicist. Having studied the earthquakes in Switzerland, he has attributed them, not without reason, in certain particular cases, to the falling-in of subterranean caverns caused by the dissolving-out of such substances as salt or gypsum by water which has penetrated beneath the surface. Such a collapse would, without doubt, cause a very appreciable shock at the surface of the earth. This theory may apply to certain special cases; but it remains to be seen if it applies to the Spanish earthquakes.

There is a fourth which is at present in favor in Germany among nearly all geologists of that country, and it has also been accepted by some in other countries. In France it has not been so well received: nevertheless, there are eminent men who entertain it. It is based upon geological observations. There are no geologists, indeed, who, observing the walls of the cracks in the metamorphic rocks, for instance, have not been struck by the fact that these beds, originally deposited in a horizontal position, have been raised and broken. There have evidently been movements of extreme importance, since rocks that were originally connected and regular are now in the greatest disorder. Now, it is certain that these movements could not have been produced without superficial shocks at the moment when the fissures were made. Therefore there must have been earthquakes in all geological epochs, even the most ancient, which are exactly comparable with those of to-day. But reciprocally, if these ancient foldings have produced earthquakes, why are not the present earthquakes the result of analogous phenomena?

You see that the theory is perfectly regular up to this point. It is only necessary to know (the difficulty is merely thrown back in time) what is the origin of these foldings, of these fractures. Why these out-throws, these subsidences, these convolutions? We then arrive at a very old explanation, given by geologists, and still admitted by many *savants*. It is that the earth is continually cooling, and so contracting. The superficial crust has reached a nearly constant temperature; but this is not true of the liquid portions adjacent to it, where the temperature must be very high, though constantly cooling. In cooling, its volume becomes less, and its contractions cause foldings and fractures in the solid crust. This theory is rather old, it is true, but there is no better theory at present.

As to the Spanish earthquakes, it seems to me, that, of these four theories, only two should receive any attention.

The question is, therefore, whether there are fissures, bendings, and faults beneath the surface, or whether the water is dissolving out caverns. In a

[1] A communication to the French geographical society, on Jan. 23, by Mr. FOUQUÉ, professor of geology in the Collége de France, and chief of the commission appointed by the Academy of sciences to study the Spanish earthquakes.

word, the subject for research is whether one of the last two theories will apply to the case in question. You will notice, moreover, that each of these theories presumes a geological cause. It is in part, I think, this idea of the connection between earthquakes and the movements far below the surface, that has influenced the Academy of sciences in choosing a geologist to examine the phenomenon.

In my turn, — and for the same reason as the Academy of sciences, — I have taken geologists as collaborators. Those who accompany me are Messrs. Michel Lévy and Marcel Bertrand, members of the geological survey of France, and mining engineers of great competence. The third who accompanies me is Professor Barrois, of the Faculty of science at Lille, an eminent geologist, who is well acquainted with the Spanish soil.

I have, then, as my associates, three geologists, perfectly competent to study all the facts that are usually investigated in earthquakes, — the propagation of the motion, the direction of the shock, and the place of greatest intensity. They are also capable of determining the relations which exist between the superficial action of an earthquake and that which may be going on at great depths. Geologists, when they travel over the surface of a piece of ground, see not only the superficial beds, but, by a sort of instinct, they divine the character of the deeper extensions. Sometimes they are mistaken, — they are not infallible, — but still, in the most cases, they are able to determine the constitution of the deep strata. This, then, is one special point which we shall endeavor to determine.

We wish, from the study of the superficial deposits, to deduce its geological structure at a certain depth. On the other hand, with the means which we possess to-day, it is possible to determine approximately the depth from which an earthquake shock originates. We have two methods for this. One, which is founded upon very precise and delicate observations, has been proposed by Mr. Seebach: it is based upon the determination of a series of points, in which the oscillations are felt at the same moment. These observations are extremely difficult to obtain.

There is another, older method, due to the English physicist, Mallet. The system of observations proposed by him is based upon the examination of the cracks in the land after an earthquake. These fractures are, in nearly every case, normal to the direction of the shock; and, when one studies them carefully, the direction of these normals is sufficient to fix their points of convergence, and hence the origin of the shock.

The methods of which I have spoken are not purely theoretical: they have been applied five or six times by Germans, Italians, and English; but, unfortunately, the French have not yet used them. They have given very interesting results; as, for instance, in the last earthquake at Ischia, it has been shown that the cause of the concussions came from a depth of from twelve hundred to eighteen hundred metres at the most. Between twelve hundred and eighteen hundred metres there is certainly a considerable range; but one would have expected to find that the shock came from a much greater depth. Consequently much is already accomplished, when we can limit the origin of the phenomenon to a space so restricted.

I said that we were able to apply these two methods, the one certainly, the other probably. We may thus ascertain the depth of the earthquake's centre. If, on the other hand, we are able to determine by geological observations the constitution of the earth at this point, we shall have obtained a datum extremely important, and we may be able to accept one of the two theories, or so to limit one or the other as to make it agree better with the facts.

These are the objects of our mission, these the things we count on accomplishing. You will see that it is very simple. I hope that we shall obtain satisfactory results. I do not dare to promise that we shall; but I do promise you that we shall study Andalusia, or a portion of this province, with care, and that we shall bring back data of geological interest and importance from this very curious country.

SEISMOLOGICAL NOTES.

THE earthquakes of the last year in England have, like those in this country, aroused an interest in seismometry; and the committee of the Scottish meteorological society, who have charge of the Ben Nevis observatory, have asked Professor Ewing (whose work in Japan we recently noticed [vol. iv. p. 516], and who is now professor of engineering in University college, Dundee) to institute earthquake observations on the top of Ben Nevis. Professor Ewing has received a grant of a hundred pounds from the committee controlling the government grant for scientific investigation, and will proceed to set up apparatus to detect, and probably to record, minute earth-tremors, and also slow changes of level of the ground.

In connection with the recent Spanish earthquakes, it is interesting to note that we have accidentally brought into prominence a new kind of seismoscope. In *Nature*, vol. xxxi. p. 262, Mr. Ellis of the Royal observatory at Greenwich states that the continuous photographic records of the declination and horizontal force magnetometers both show a simultaneous disturbance, different from the ordinary magnetic disturbances, occurring on the evening of Dec. 25, a few minutes after the reported time of the severe earthquake in Spain on that date. No ordinary magnetic disturbances were recorded on this and neighboring dates, and the earth-current registers showed no change; so that there would seem to be little if any reason to doubt that the unusual disturbances recorded were caused by the swinging of the magnets on their suspending fibres, due to the shaking of the points of suspension by the Spanish earthquake. If some method were devised of photographing the lateral swing of the magnets in two azimuths at right angles, in addition to the present torsional swing as magnetometers, these instruments could, perhaps, be made very sensitive seismoscopes as well, and the accuracy of the time-record would only depend upon